A Simple Dispersion Measurement of Fiber Gratings by Interferometric Technique

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ABSTRACT

A simple dispersion measurement of fiber gratings using an un-balanced Michelson interferometer is proposed. A broadband source and an optical spectrum analyzer are used to scan the interference spectrum, and then the group time delay can be obtained rapidly by Fourier transform processing the interference spectrum. We measured the group time delays of a uniform-period FBG, a chirped FBG, an arrayed-waveguide grating interleaver, and a thin-film filter type OADM by an un-balanced Michelson and Mach-Zehnder interferometers, respectively. The experimental results excellent match the measured results of the optical network analyzer. The experimental repeatability is shown to be better than 1ps.

Keywords: Un-balanced Michelson interferometer, fiber gratings, group time delay, Fourier transform processing, Mach-Zehnder interferometer.

1. INTRODUCTION

Fiber Bragg gratings (FBG) have recently become an enabling technology that provides convenient, cost-effective, and reliable solutions to some of the important problems in the high bit-rate optical communication systems [1]-[4]. Measurement of chromatic dispersion is an essential technique for developing a new fiber grating device. Although the modulation phase-shift method [5] is usually applied to measure the chromatic dispersion of a fiber-optic device due to its accuracy and repeatability, it requires the complicated setup and expensive modules such as high-speed optical modulator and detectors. To simply the dispersion measurement of a fiber grating, the techniques of the Michelson interferometer have been proposed to measure the wavelength-dependent reflective differential delay characteristics along the fiber grating [6, 7]. However, conventional interferometric dispersion measurement methods require either an expensive tunable laser or an accurate step-shift system for varying the reference path length. In this paper, we propose a simple and accurate interferometric dispersion measurement technique of the fiber gratings using Fourier transform spectroscopy. This method just requires a broadband source and an optical spectrum analyzer to scan the interference pattern in wavelength domain. Applying the optical spectrum analyzer to rapidly measure the interference spectrum, we can effectively avoid the perturbation in the environment. We will demonstrate the dispersion measurement results of a uniform-period FBG filter and a chirped FBG. The results quite agree with the data measured by using the optical network analyzer (Advantest Q7760). Furthermore, we also applied the proposed method to measure the dispersion of the transmission device. The group time delays of an arrayed-waveguide grating (AWG) interleaver and a thin-film filter type OADM were measured by using a un-balanced Mach-Zehnder interferometer and the proposed Fourier transform processing. The measured group delays also excellent match the results of the optical network analyzer.

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2. PRINCIPLE OF MEASUREMENT

The dispersion measurement setup for a fiber graing consists of an un-balanced Michelson interferometer, as shown in Fig.1. The ASE source and optical spectrum analyzer have been used to obtain a wide spectrum range measurement in a single fringe scan. A test FBG is connected one arm of the interferometer. A fiber collimator and a gold-coated mirror are used in the other arm of the interferometer to control the path length difference between the two arms. A broadband polarizer and two collimators are used to obtain a linear-polarized incident light so that a fringe pattern with distinct visibility can be measured.

The interference spectrum of the un-balanced Michelson interferometer measured by the optical spectrum analyzer can be expressed as [7]

$$I_{inter}(\lambda) = I_{DUT}(\lambda) + I_{air}(\lambda) + 2\sqrt{I_{DUT} I_{air}}\, cos\left(\frac{2\pi}{\lambda} \Delta nL + \varphi(\lambda)\right) \quad (1)$$

where I_{DUT} and I_{air} are the intensity reflection spectra of the DUT and reference arms, respectively, and ΔnL is the optical path-length difference between the two arms. The phase term $\varphi(\lambda)$ is the wavelength-dependent phase delay of a tested FBG device. According to (1), the inverse Fourier transformation $I_{inter}(t)$ of the measured interference spectrum consists of the -1, 0, and +1 order harmonic components. If the optical path-length difference ΔnL is much enough to avoid the overlap of the 0, and +1 order harmonic components, then the component $\sqrt{I_{DUT} I_{air}} \cdot exp[i\varphi(\lambda)]$ can be calculated from the time domain response $I_{inter}(t)$ by using the band-pass filtering and the Fourier transform processing. Finally, we obtain the argument $\varphi(\lambda)$, and then evaluate the group time delay of the tested device by using the following equation [1]

$$\tau_g(\lambda) = -\frac{\lambda^2}{2\pi c} \cdot \frac{d\varphi}{d\lambda} \quad (2)$$

where c is the velocity of the light in vacuum.

In contrast to the previous balanced Michelson interferometer [7], the spectra I_{inter}, I_{DUT}, and I_{air} must be all measured and then the wavelength-dependent phase delay $\varphi(\lambda)$ can be calculated from the inverse Fourier transformation of the spectrum I_{inter} by subtracting the contributions of I_{DUT} and I_{air}. Thus, we note that the proposed unbalanced interference method is more simplified than the balanced interference configuration in the experiment and calculation steps.

3. RESULTS AND DISCUSSIONS

In order to verify the accuracy of the above measurement, we have measured a uniform-period FBG and a linear-chirped FBG with the 0.005nm/mm chirp of the Bragg wavelength. Fig.2 (a) shows the measured spectrum I_{inter} of the uniform-period FBG filter using the proposed setup with the optical path-length difference $\Delta nL \approx$ 8mm. The optical path-length difference ΔnL is set to zero where the fringe number in the stop-band is minimum. Using the above-mentioned calculation procedure, the phase $\varphi(\lambda)$ and the squared amplitude of the complex reflection coefficient is obtained and shown in Fig.2 (b). The group time delay of the uniform-period FBG filter is determined by the equation (2) and shown in Fig.2 (c) where the dash line is the measured result by the optical network analyzer (Advantest Q7760). We notice the group delay obtained by the proposed method is in good agreement with the measured result of the optical network analyzer.

In order to verify the repeatability of the proposed measurement, we have repeatedly measured the group time delay of a chirped FBG with the 0.005nm/mm chirp of the Bragg wavelength for five times by using the un-balanced Michelson interferometer with the optical path-length difference $\Delta nL \approx$ 10mm. The group time delay of the chirped FBG from the five repeated measurements and the retrieved reflection spectrum are shown in Fig.3. The repeatability is better than 0.5ps in the 3dB bandwidth of the chirped FBG.

In fact, we believe that the dispersion of a transmission device can also be measured by using an un-balanced Mach-Zehnder interferometer and the above-mentioned data processing. In order to verify the validity of the expectation, we have also measured the dispersion of an AWG interleaver and a thin-film filter type OADM by using the modified interferometer shown in Fig.4. The measured spectra I_{inter} of the AWG interleaver and the thin-film filter type OADM are shown in Fig.5 (a) & (b), respectively. Using the proposed calculation procedure, we determine the phases delays and the transmittance of the two devices and show in Fig.5 (b) & (d). Thus, the group time delays of the AWG interleaver and the thin-film filter type OADM are obtained using the equation (2) and shown in Fig.5 (e) & (f), respectively, where the dash lines are the measured results by the optical network analyzer. One can see that the measured group delays by the proposed method also excellent match the measured results of the optical network analyzer.

4. CONCLUSIONS

We have proposed a simple and accurate dispersion measurement of the fiber grating using the un-balanced Michelson interferometric technique. In this measurement, a broadband source and an optical spectrum analyzer are used to scan the interference spectrum, and then the group time delay can be obtained from the Fourier transformation of the interference pattern. We not only measured the chromatic dispersions of a uniform-period FBG and a chirped FBG by an un-balanced Michelson interferometer, but also measured the group delays of an AWG interleaver and a thin-film filter type OADM by an un-balanced Mach-Zehnder interferometer. The experimental results excellent match the measured results of the optical network analyzer. The experimental repeatability is shown to be better than 1ps. Because of its accuracy and repeatability, as well as simplicity in experimental setup and operation, we believe this technique will become a very powerful method for measuring chromatic dispersion of fiber-optic passive devices.

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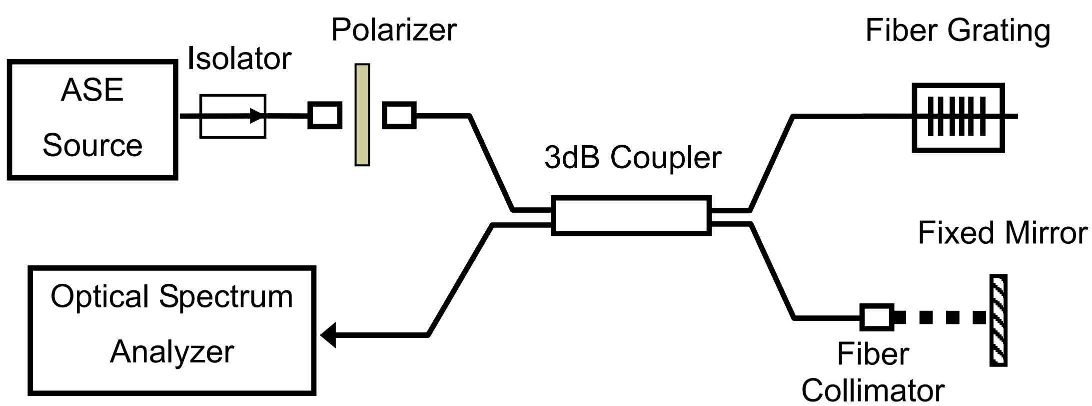
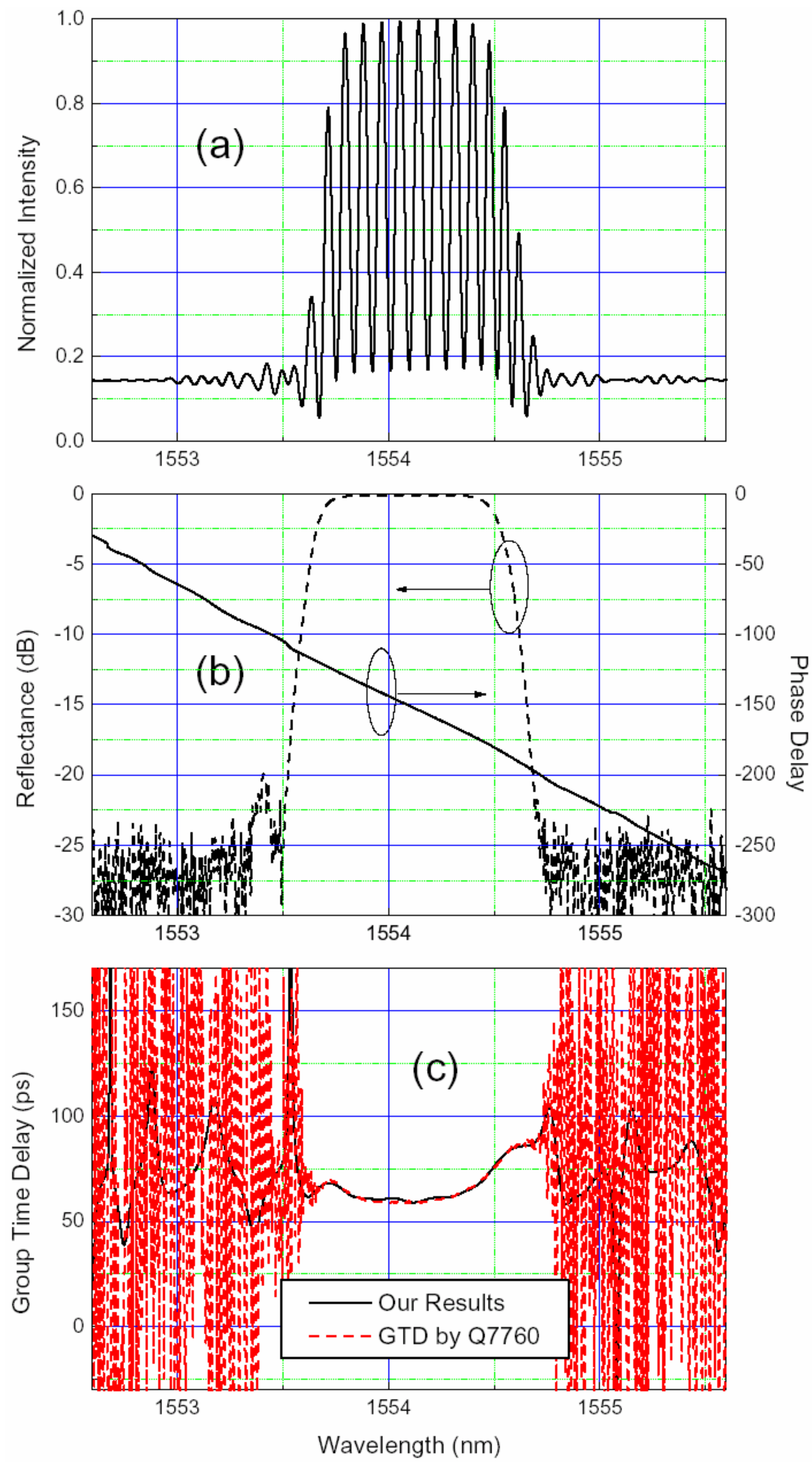


Figure 1. Un-balanced Michelson interferometer setup



(a)
Normalized Intensity
1.0
0.8
0.6
0.4
0.2
0.0
1553
1554
1555
(b)
Reflectance (dB)
Phase Delay
0
-5
-10
-15
-20
-25
-30
-50
-100
-150
-200
-250
-300
(c)
Group Time Delay (ps)
150
100
50
Our Results
GTD by Q7760
Wavelength (nm)

Figure 2. (a) Measured interference spectrum, (b) retrieved reflection spectrum, phase of complex reflection coefficient, and (c) calculated group time delay of the unform-period FBG.

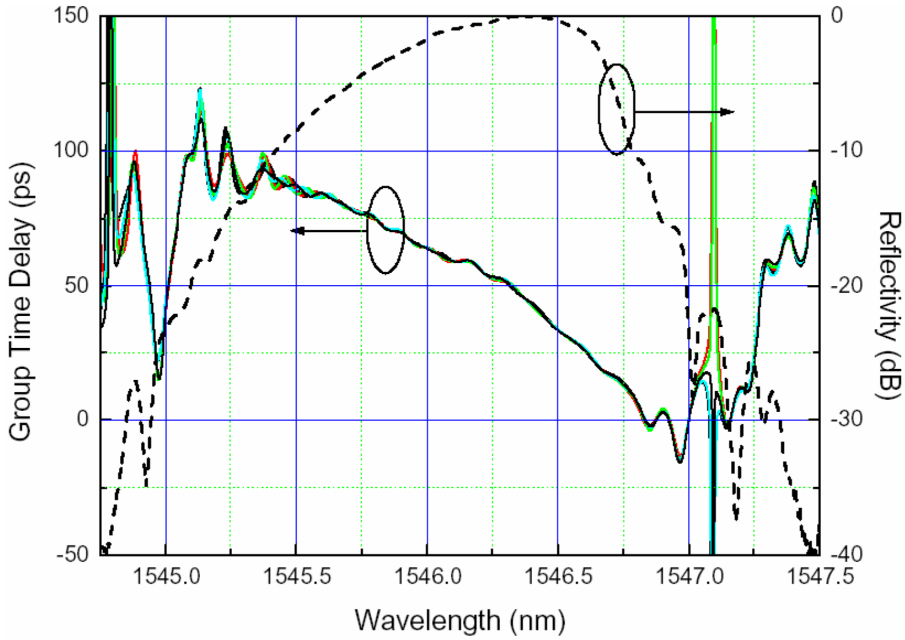


Figure 3. Group time delay of the chirped FBG against wavelength from the five repeated measurements and the retrieved reflection spectrum

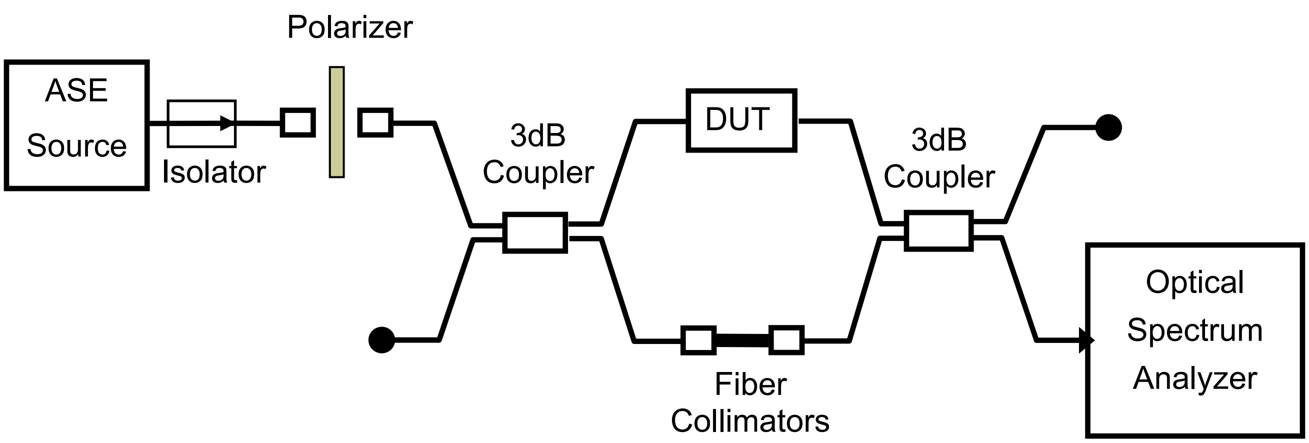


Figure 4. Un-balanced Mach-Zehnder interferometer setup

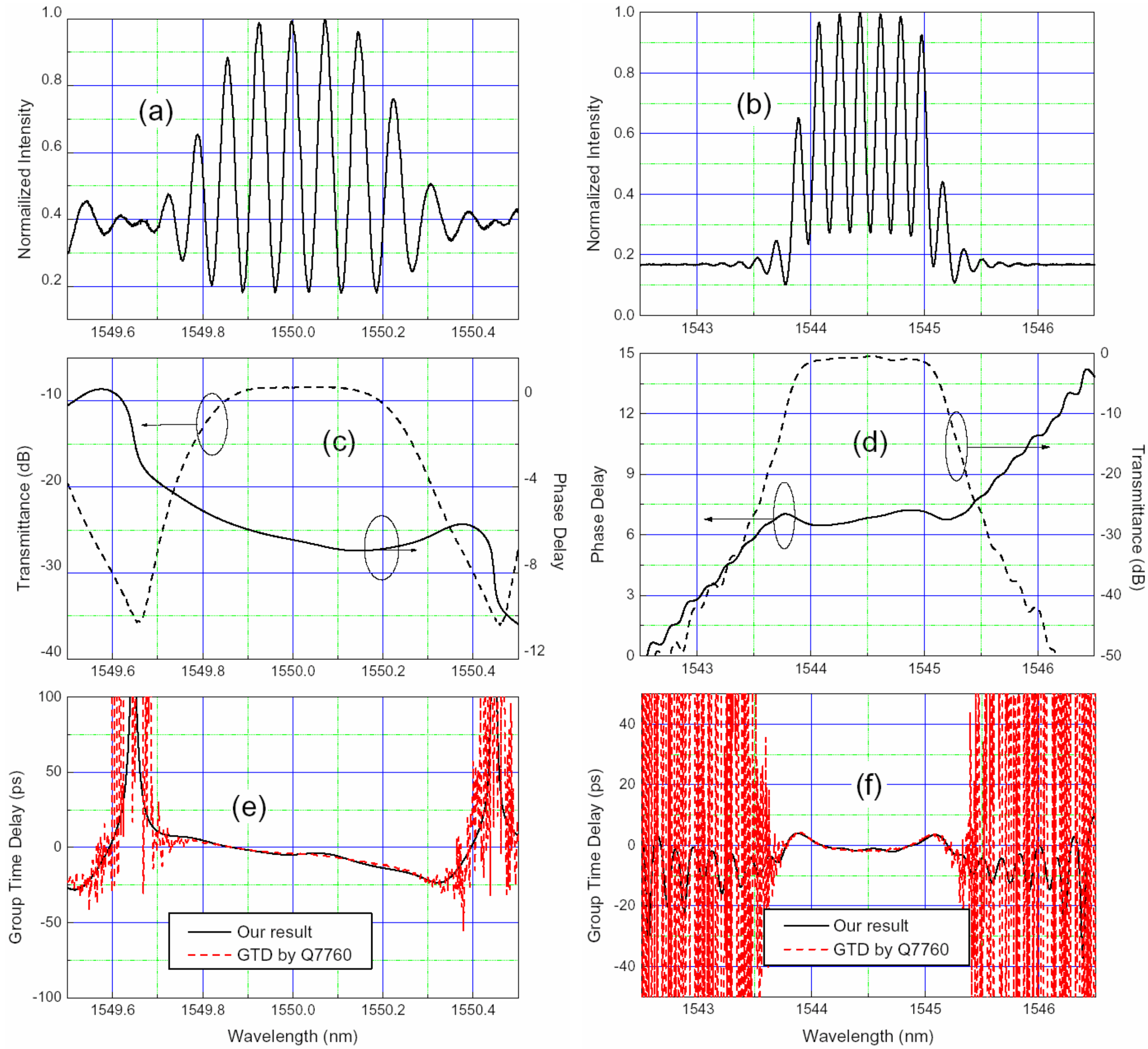


Figure 5. (a) & (b) Measured interference spectrum, (c) & (d) retrieved transmission spectrum, phase of complex transmission coefficient, and (e) & (f) calculated group time delay of the AWG interleaver and the thin-film filter type OADM.